LAT 39.94629 LON -121.24964

FOREST PEST MANAGEMENT
Pacific Southwest Region

3400 Forest Pest Management
March 9, 1984

INCIDENCE OF FOMES ANNOSUS IN MIXED CONIFER AND TRUE FIR FORESTS IN NORTHERN CALIFORNIA

REPORT NO. 84-11

Gregg DeNitto, Plant Pathologist
Forest Pest Management

John R. Parmeter, Jr., Professor of Plant Pathology
University of California
Berkeley, California

Garey Slaughter, Staff Research Associate
University of California
Berkeley, California

Mark Schultz, Research Assistant
University of California
Berkeley, California

USDA, FOREST SERVICE, PACIFIC SOUTHWEST REGION
State and Private Forestry, Forest Pest Management
630 Sansome Street, San Francisco, California 94111

ABSTRACT

A survey of twelve National Forests in northern California revealed that Fomes annosus infects approximately six million live true firs, about 2% of the total number. Annosus root disease was also involved in the death of nearly 20% of the recently killed true firs. Infection centers can be found throughout the more than 3.2 million acres that support white and red fir, although the occurrence of the disease is somewhat dependent on the geographic location. The incidence is lower in the northwestern part of the state. The estimated area infested is 586,000 acres.

Several stand, site, and tree characteristics were examined to determine their relationship with the incidence of F. annosus. Fomes annosus tended to occur in pure, dense red fir stands that had been previously logged. The fungus tended to be in older and larger trees.

INTRODUCTION

True firs, principally white fir (Abies concolor) and red fir (A. magnifica), comprise about one-third of the net volume of sawtimber on timberland in National Forests in California and about one-fifth of the net volume on other timberlands in the state (Bolsinger, 1980). These species accounted for 19% of the log volume consumed by mills in the state in 1976 (Bolsinger, 1980). They grow on over 3 million acres at the moderate to higher elevations of California. White fir is a component of the mixed conifer type, with an increasing proportion at higher elevations until it becomes the dominant species in nearly pure stands. At elevations above this, the amount of red fir increases until it eventually forms pure stands.

Fomes annosus causes a root and butt decay of most species of conifers in California. It was originally reported in California in 1909 and has subsequently been reported to be widespread throughout most of the coniferous forests in the state (Bega and Smith, 1966). It is one of the most damaging forest tree diseases in the state, killing the roots of resinous conifers and causing a heart rot of the roots and butt log of non-resinous conifers.

A statewide evaluation of the incidence of this fungus has not previously been attempted. Numerous smaller surveys on a forest or stand basis have indicated that infection of true firs by F. annosus is frequent and might be having a significant impact on this resource. A survey on part of the Eldorado National Forest in 1973 found that F. annosus was a contributor to 40% of the white fir mortality and 70% of the red fir mortality (unpublished, FPM). A similar evaluation in 1974 of the Stanislaus National Forest revealed that over 60% of white fir mortality and 25% of red fir mortality involved F. annosus (unpublished, FPM). In both situations, the fir engraver, Scolytus ventralis, was also present in dead and dying true firs. Cobb et al. (1974) looked at white firs in two locations in the central Sierra and found F. annosus associated with 71% and 79% of the recent mortality. They also found an

association between top-kill caused by _S. ventralis_ and _F. annosus_ infection. Observations by Parmeter, Schultz, and Slaughter in some true fir stands without mortality have revealed infection of 2 to 5% of the live true firs by _F. annosus._

Because of the potential for annosus root disease to cause sizeable annual losses in true firs in California and because of the lack of information on the importance and impact of this disease, Forest Pest Management (FPM) entered into a five-year cooperative agreement with the Department of Plant Pathology, University of California, Berkeley in 1977. A damage survey to determine the incidence of and mortality caused by _F. annosus_ in true fir was part of this agreement.

Three objectives were established for the damage survey of mixed conifer and true fir types on commercial forest lands of 12 National Forests[1/] in California.

1. Estimate the true fir mortality with _F. annosus._

2. Estimate the annual true fir losses from windthrow.

3. Estimate the incidence of _F. annosus_ in living true fir.

BIOLOGY OF _FOMES ANNOSUS_

Infection of true firs by _F. annosus_ begins when airborne spores are deposited on freshly cut stump surfaces or basal wounds of true firs. After germination, the fungus grows into the stump and root system, decaying the wood and killing small roots. When root contact occurs with roots from surrounding live true firs, the fungus can cross over and begin decaying this new root system. This type of local spread results in the formation of expanding disease centers.

Fomes annosus is not a strong competitor in attacking dead tissue, therefore, it must rapidly colonize new stumps and wounds to be successful. Once established in a stump-root system, however, it may persist as a saprophyte for many years, the length of time depending in part on the mass of woody tissue available to the fungus. After occupying woody tissue it will slowly decay the moist tissue, which can result in the development of cavities in stumps. These cavities function as moist chambers where the leathery, poroid conks develop and produce spores.

[1/] National Forests in the survey area included the Eldorado, Klamath, Lassen, Mendocino, Modoc, Plumas, Sequoia, Shasta-Trinity, Sierra, Six Rivers, Stanislaus, and Tahoe.

Fomes annosus can rapidly kill true fir seedlings and saplings. Larger trees usually decline slowly as roots are decayed. In unsuppressed white firs this decline may involve a reduction in height growth and reduction in needle retention in the upper crown (Ferrell and Smith, 1976). As the root system decays, the tree may be windthrown or predisposed to attack by fir engraver beetles.

SURVEY METHODS

Photo Plot Selection

This root disease survey utilized plots that had been selected by FPM in 1976 for a Statewide Loss Assessment Survey. The design employed random initial plot selection and subsampling with probability proportional to the amount of photo-detected mortality (PPS).

Each township having commercial forest land on a National Forest was stratified by major timber type. Each of these townships were numbered and divided into 81 potential photo plots. Plot numbers were drawn randomly until a sufficient number of plots for sub-sampling (photographing) in the smallest stratum were drawn. This resulted in a total of 168 randomly selected plots. Normal-color, stereo aerial photographs (1:10,000) were taken of each of these plots. A 247-acre square was delineated on each set of photo plots. These were viewed stereoscopically and inspected for the presence of true firs. If a delineated area had a 2.47-acre stand containing 10-80% true fir, the boundary of the fir stand was drawn on the photo and labeled "mixed fir". If stands were more than 80% true fir, they were delineated separately and labeled "pure fir".

Ninety plots each had at least 2.47 acres of mixed or pure fir and qualified for the survey. Nine of these plots were deleted because they occurred on productive-reserved land (wilderness or RARE II). Recently dead true fir trees (dead 3 months to 2 years prior to photo date, with faded tree crowns) were identified and marked on each fir plot.

Ground Sample Selection

Two separate independent samples were drawn from the 81 plot base for further evaluation. One sample consisted of true fir stands (green plots) and the other consisted of true fir stands with photo-detectable, recent true fir mortality (mortality plots).

a. In the first sample thirty green plots were selected with probability proportional to the area (PPS) within each plot supporting true fir stands. Because of replacement, a total of 37 green plots comprised the sample for statistical analysis.

Ten green cells of 1/6-acre each were selected at random with replacement within the delineated fir stand on each green plot. A second set of 10 cells was also selected and numbered serially. Cells were identified and selected using a digitizer-minicomputer system (Demars, 1980). Using the aerial photos, the green cells were located on the ground.

Data were collected on 300 green cells. A green cell was acceptable if it had at least one live true fir between 4-21 inches dbh. If an acceptable true fir was not present, then another cell was selected serially from the secondary list of 10.

b. In the second sample twenty-five mortality plots were selected with probability proportional to the number of dead fir trees identified within the delineated fir stands on the aerial photos. Because of sampling with replacement, 35 mortality plots comprised the sample for statistical analysis.

Up to 10 mortality spots were selected for ground verification on each of the selected mortality plots. When more than 10 spots were photo-detected, then 10 spots were selected with probability proportional to the number of dead fir trees identified within the mortality spots on the aerial photos. When a mortality spot was located on the ground, a 1/6-acre cell was established with the recently dead firs in the center. A mortality cell was acceptable if at least one of the photo-detectable dead firs had died within 2 years of the ground check. Data were collected on 153 separate mortality cells.

Data Collection

One live true fir on each cell was sampled by selecting at random a tree of cuttable size (4-21 inches dbh) within the cell boundaries. A total of 451 live true firs were sampled. Recently dead true firs were divided into two groups, photo-detectable and non-photo-detectable. For each group in each mortality cell, one tree was sampled randomly from any number of dead trees up to five. If there were more than five trees in either group, an additional tree was selected for each additional five trees. A total of 240 dead true firs were sampled.

Live and dead sample trees were felled and a full 1/2-1 inch thick disc was cut from the stump at 12 inches above the ground. The disc was sealed in a plastic bag and inspected after 7 days for the conidial state of F. annosus. If the dead tree was larger than 21 inches dbh, then a pie-shaped wedge was removed from the base of the standing tree and treated as a disc. Green trees larger than 21 inches dbh were not sampled.

Ground data collection was identical on both mortality and green cells. Stand and site parameters were measured and recorded. The cells were inspected for positive evidence of F. annosus (conks), and for probable evidence (either suspicious decay, evidence of continuing mortality over many years, or both).

The acreage of the survey area was determined during the process of plot stratification and identification. Acreage estimates previously derived by FPM were modified proportional to the average amount of true fir type delineated on the photo plots for each forest type. These modified true fir acreages by forest type were then summed to yield the total acres of true fir stands used as the basis for the survey area.

RESULTS

The estimated number and volume of live and dead true firs in the survey area are presented in Table 1. This table also displays the estimated number and volume of trees that were infected by F. annosus. The number of trees was converted to a per acre basis for the 3,281,000 acre survey area.

The relation of size class to mortality and to infection by F. annosus is shown in Table 2. The smaller size class (dbh less than 12 inches) had the greater number of recently dead trees. The volume of dead trees was greater for the larger size class. Similarly, the smaller size class had a greater number of dead true firs that were infected by F. annosus. The volume of dead infected true firs was greater in the larger size class.

This survey did not attempt to delineate exact areas occupied by F. annosus. In this survey, when F. annosus was identified in a 1/6-acre cell, the entire cell was considered occupied by the fungus. Expansion of this information revealed an estimated total infested area of about 586,000 acres. About one out of six cells had an infection center.

The occurrence of stand, site, and tree characteristics with the presence of F. annosus were analyzed by chi-square analysis to determine if a relationship existed. This type of analysis can indicate trends, but the results should not be considered definitive until more detailed analyses are done. These trends of each independently analyzed characteristic are displayed in Table 3. Data from both the green plots and mortality plots were combined for the analyses.

Only one windthrown tree was located on all of the plots during the course of the survey. This was insufficient to produce any expanded estimates of windthrow for the state.

DISCUSSION

Annosus root disease is involved in a substantial amount of the true fir mortality in northern California. Much of this annosus-related mortality, however, is in the smaller size classes (average volume per tree = 8 cu.ft.). These small trees barely reach present merchantability standards and, in most situations, do not justify the expense of a salvage harvest. Also, because of their small size and the decay susceptibility of true firs, these trees would have to be removed rapidly if they were to be utilized. It is, therefore, unlikely that this volume would leave the forest and go to a mill. This mortality constitutes about 1% of the Region's annual sale target, and, therefore, has negligible impact on the supply of timber from the National Forests.

The number and volume of live true firs infected by F. annosus is also relatively small compared to the total. It is not known how long these trees will survive, nor what effect the fungus is having on tree growth. Only if all of these trees died within a relatively short period of time would there likely be a substantial effect on the supply of timber.

TABLE 1. Incidence of *Fomes annosus* (FA) in Live (4-21 inches dbh[a]) and Dead (≥4 inches dbh[a]) True Firs in National Forests of Northern California.

	Number	Volume (cf[b])	Number/ Acre[c]
Live Trees	392,449,000		119.6
Live Trees with FA	5,985,000	145,771,000	1.8
Dead Trees	2,850,000	73,138,000	0.9
Dead Trees with FA	554,300	9,074,000	0.2

[a]dbh = diameter at 4.5 feet above the ground.
[b]cf = cubic feet.
[c]Based on a survey area of 3,281,000 acres.

TABLE 2. Number and Volume (mcf[a]) of Recently Killed True Firs Infected by *Fomes annosus* (FA) in National Forests of Northern California.

	Diameter (inches), Breast Height[b]					
	<12			> 12		
Dead Trees	Number (X 1000)	Volume	Number/ Acre	Number (X 1000)	Volume	Number/ Acre
Total	2,011	11,197	0.61	839	61,941	0.26
With FA	457	3,512	0.14	97	5,562	0.03

[a]mcf = thousand cubic feet.
[b]Breast height = 4.5 feet above the ground.

TABLE 3. Stand, Site, and Tree Characteristics Associated with *Fomes annosus* in True Fir[a].

Characteristic	*Fomes annosus* in true fir occurs:
Geographic region	less often in northwestern California
Forest type	more often in red fir type, less often in mixed conifer and pine types
Species composition	more often in pure fir stands (> 80% fir), less often in mixed stands (< 80% fir)
Stand density	more often with increasing absolute density (basal area)
Cutting history	more often in previously logged stands, more often in a tree when it is within 16 feet of a fir stump
Fir mortality	more often in mortality centers with less than 5 recently killed true firs
Brush history	less often when evidence of brush is present
Tree age	more often in older trees
Tree size	more often in larger trees, both diameter and height
Radial growth	more often in faster growing trees
Terminal growth	more often in trees that have slowed in terminal growth
Wetwood	more often in trees without wetwood

[a]see the discussion for a more detailed explanation.

These estimates of incidence are low by a substantial, but unknown amount for several reasons. The fungus cannot be detected by disc examination unless it has reached the root collar or stump area of the stem, therefore, infections on roots were not detected. Symptoms of crown decline are not expressed until a large portion of the root system has been destroyed. Therefore, many infected trees may have gone undetected because of the difficulties in determining infection. A second limitation is that no live trees larger than 21 inches dbh were felled and sampled. Because available evidence indicates that the incidence of *F. annosus* increases with tree size, the estimated numbers and volumes of live infected trees would have been markedly increased by the inclusion of data on trees over 21 inches dbh.

Based on the estimates of losses presented here it would appear that *F. annosus* is not having a substantial impact on the true fir resource. That is, *F. annosus* is not interfering with the attainment of regional objectives, nor is it significantly reducing regional timber outputs. We do not know to what extent the incidence of *F. annosus* will increase in the future, but it is expected to increase as stand activities continue. An unanswered question is what potential effect *F. annosus* will have on regenerated stands that are managed to maximize timber production. We have only preliminary information regarding this question.

The persistence of *F. annosus* in fir stumps and root systems and the ability of the fungus to infect regeneration is not known. Observations of the fungus in pines indicates that root disease centers may be active for at least 30 to 40 years. However, fir stumps may be more rapidly colonized by saprophytic organisms than are pine stumps, restricting *F. annosus* and its ability to attack surrounding trees. On the other hand, *F. annosus* conks can be found in fir stumps that were created 20 or more years previously. Active annosus root disease centers in true fir have not been observed long enough to determine their longevity, therefore, estimates on the loss of productivity of a site are speculative.

The high incidence of *F. annosus* in the more than 3 million acres with true fir may have a considerable effect on future management. Yields from these lands may be less than expected. Future generations could be seriously impacted as regeneration fails and maximum productivity is not attained. In addition, timber cutting in these infected and surrounding lands may cause an increase in the amount of infection and the resultant decrease in productivity.

The number of dead true firs found in this survey is higher than what was found by the FPM Staff in a statewide survey in 1979-80. The statewide survey identified approximately 0.04 dead true firs per acre, in comparison with 0.9 trees per acre in this survey. Several reasons account for this discrepancy. In the FPM survey, trees smaller than 12 inches dbh were not counted, while the lower limit was 4 inches dbh in this survey. The FPM survey was based on mortality selected by photointerpretation and had omission errors (i.e., dead trees not identified

on the photos) that were not included in the base. The green plots in this survey were selected without regard to mortality and did not have omission errors. This latter approach is more realistic to determine the total number of dead trees, although many of them may be in the smaller size classes.

The average size of infected dead firs was smaller than that of infected live firs. Because of the maximum diameter limit on live trees examined, the difference is actually greater than the numbers indicate. This suggests that small infected trees are more likely to die than are larger infected trees. Reasons for this are unknown, but it may be that small trees are often suppressed by competition and cannot withstand the additional stress of root disease. Further, small trees generally have smaller root systems, and it may take less time for F. annosus to destroy some critical proportion of the root system.

Defining what types of stands and sites have higher incidences of F. annosus would begin to tell us where to expect less than maximum timber production. Likewise, from this information we could begin to formulate methods to regenerate and manage stands to minimize the impact of the disease. The present study was not designed to collect information for this type of risk rating system. The data gathered on stand, site, and tree characteristics do suggest some factors that should be examined more closely and that may be manipulated to lessen the disease.

Characteristics that may be influenced by stand management include stand density, species composition, stand age, logging activity, and rate of growth. Various relationships were found between these factors and the incidence of F. annosus. One of the stronger relationships was between logging history and annosus root disease. This is to be expected when the principal avenue of infection is probably through freshly cut stump surfaces. The relationship with logging also corresponds to other factors, such as slope and topography because of the ease of accessibility.

There was also a strong relationship with the number and species of stems. The purity of species composition influences F. annosus because of the method of local spread via root contacts. The transference of the fungus between roots of the same species appears to occur more readily than between different species. Some evidence has been accumulating that indicates host specialization may be present in F. annosus (Worrall, Parmeter, and Cobb, 1983). This may explain in part why infected pines rarely are observed around a F. annosus-infected white fir stump. The presence of pines in a stand may reduce tree-to-tree spread of F. annosus between white firs because of the interference in fir-to-fir root contacts. This may also explain the higher probability of finding F. annosus in red fir stands. Red fir is usually found in "pure" stands or mixed with white fir, whereas, white fir is more commonly a component of mixed conifer stands with ponderosa pine. The influence of density is a result of the greater number of root systems and the higher number of root contacts. True fir stands usually have a greater number of stems per acre than do mixed conifer stands.

Mortality of true firs infected by _F. annosus_ occurs slowly, as does the local spread. This causes a gradual development of root disease centers. Most mortality spots were found to have fewer than five recently killed true firs. This supports the concept of a slow killer, although the rate is not known. Field observations have indicated that stands infested with _F. annosus_ often have one or more mortality centers with a "progressive" appearance, that is, infected stumps surrounded by "rings" of trees that have died over time, the oldest death nearest the stump.

The incidence of _F. annosus_ was related to tree size and age. Tree age usually influences size. Several factors come into play here. Older trees have had a longer time in which they have had the opportunity to be infected. This includes exposure to a number of wounding agents. Although no relationship between fire scars and infection was found in this survey, they have been suggested as a primary means of infection of true firs in natural, undisturbed stands (Hepting, 1971). The opportunity for basal scarring from logging activities could also increase the number of infection sites. Generally, the larger the tree the larger the root system. Large root systems will occupy greater volumes of soil, thereby increasing the probability of contact with infected stumps and roots.

Growth rate provides an interesting anomaly. Most diseases cause a decrease in the rate of growth of infected individuals. Infected true firs actually grew faster radially, although terminal growth slowed down. Ferrell and Smith (1976) identified a reduction in terminal growth as a possible indicator of white firs infected by _F. annosus_. Height growth tends to be more independent of stand density and competition than radial growth which is strongly influenced by it (Smith, 1962). Height growth is more a function of site quality and mineral and nutrient availability. A decreased root system may be functioning to decrease mineral and nutrient uptake, thereby essentially reducing the site quality. Radial growth, on the other hand, may be increasing for some trees as they are released as a result of decreasing stand density because of the mortality that occurs in annosus root disease centers.

The presence of brush, or remnants of it, indicates that the present stand was established in a brush field. The brush field could have been a result of a catastrophic wildfire that eliminated the previous stand. The lack of true firs during an extended period of time would have allowed the fungus to die out in any residual snags. Eventually, a new stand would have seeded in from surrounding stands and would not have been exposed to _F. annosus_ during the early part of its life. The heat of the fire may also have had a deleterious effect on the fungus by destroying woody host material and by causing some microbiological changes in the soil (Harvey, Jurgensen, and Larsen, 1979). A deleterious effect of heat on another root disease fungus, _Armillaria mellea_, has been demonstrated (Munnecke, Wilbur, and Darley, 1976).

This report supplies information on the survey results. This will be followed with a report on management guidelines that could mitigate the effects of this root disease.

LITERATURE CITED

Bega, R.V., and R.S. Smith, Jr. 1966. Distribution of Fomes annosus in natural forests of California. Plant Dis. Rep. 50:832-836.

Bolsinger, C.L. 1980. California forests: Trends, problems, and opportunities. USDA For. Serv. Resource Bull. PNW-89. 138 p. Pac. Northwest For. and Range Exp. Stn., Portland, OR.

Cobb, F.W., Jr., J.R. Parmeter, Jr., D.L. Wood, and R.W. Stark. 1974. Root pathogens as agents predisposing ponderosa pine and white fir to bark beetles. In Proc. Fourth Int. Conf. on Fomes annosus, Sept. 17-22, 1973, Athens, GA. 8-15 p.

DeMars, C.J. 1980. Managing tree mortality location data with a desk-top minicomputer. In Proc. of Remote Sensing for Natural Resources, An International View of Problems, Promises, and Accomplishments, Sept. 10-14, 1979, Moscow, Idaho. 69-77 p.

Ferrell, G.T., and R.S. Smith, Jr. 1976. Indicators of Fomes annosus root decay and bark beetle susceptibility in sapling white fir. For. Sci. 22:365-369.

Harvey, A.E., M.F. Jurgensen, and M.J. Larsen. 1979. Role of forest fuels in the biology and management of soil. USDA For. Serv. Gen. Tech. Rep. INT-65. 8 p. Intermountain For. and Range Exp. Stn., Ogden, UT.

Hepting, G.H. 1971. Diseases of forest and shade trees of the United States. USDA For. Serv. Agr. Handbook No. 386. 658 p. Washington, D.C.

Munnecke, D.E., W. Wilbur, and E.F. Darley. 1976. Effect of heating or drying on Armillaria mellea or Trichoderma viride and the relation to survival of A. mellea in soil. Phytopathology 66:1363-1368.

Smith, D.M. 1962. The Practice of Silviculture, 7th ed. John Wiley & Sons, Inc., New York. 578 p.

Worrall, J.J., J.R. Parmeter, Jr., and F.W. Cobb, Jr. 1983. Host specialization of Heterobasidion annosum. Phytopathology 73:304-307.